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Abstract

Reported salt levels in whole-muscle cured meat products differ substantially within and among European countries, providing substantial scope for salt reduction across this sector. The objective of this study was to identify the minimum acceptable salt levels in typical whole-muscle cured products in terms of physicochemical, microbial and sensorial properties. Salt levels in a small selection of commercial Irish meat products were determined to establish a baseline for reduction. Subsequently, eight different back bacon rasher and cooked ham products were produced with varying levels of salt: 2.9 %, 2.5 %, 2 % and 1.5 % for bacon, and 2 %, 1.6 %, 1.0 % and 0.8 % for ham. Salt reduction produced products with significantly harder texture and higher microbial counts, with no difference in the colour and affecting the sensory properties. Nonetheless, salt reduction proved to be feasible to levels of 34 % and 19 % in bacon and ham products, respectively, compared to baseline.

Keywords: Salt reduction, back bacon, cooked ham, sensory, APLSR, texture

1. Introduction

Sodium contributes to several important physiological functions in the human body including maintenance of cellular membrane potential and blood pressure. However, there is substantial evidence that excessive sodium consumption is a major contributor to cardiovascular disease, due to its ability to raise blood pressure (Cook, Appel, & Whelton, 2016; Frieden, 2016; He, Pombo-Rodrigues, & MacGregor, 2014; Mozaffarian et al., 2014). In recent years, this evidence has been challenged by different authors and institutions declaring a U or J curve for sodium consumption and risk of disease (Graudal, 2016; IOM, 2013; Mente et al., 2016). Nonetheless, there is a consensus on the high grade evidence for blood pressure reduction being associated with sodium reduction in the hypertensive population.

In most European countries the prevalence of hypertension is above 30 % (Kloss, Meyer, Graeve, & Vetter, 2015) and thus vast tranches of the European population would benefit from sodium reduction strategies in the food industry. On the basis of this evidence, the majority of European countries, under the World Health Organisation policies, have adopted strategies for dietary salt reduction towards meeting the recommended intake of 5 g salt/day—as around 90 % of the sodium in our diets comes in this form (WHO, 2013). Twelve countries have already reported reductions in population salt intake and 19 have reduced the salt content in different foodstuffs (Trieu et al., 2015).

After the bread and cereals group, the largest source of sodium (salt) in the European diet is processed meat products (Kloss et al., 2015). Average consumption of meat and meat products for the European adult population is around 1.85 g/kg body weight/day, of which 0.58 g/kg body weight/day comes from processed meat and sausages (EFSA). Whole-muscle cured meat products constitute an important share of the processed meats; with pork ham and bacon being the most consumed products within this group. It is estimated that a European adult consume around 0.19 g/kg body weight/day of pork ham and bacon (EFSA). In Ireland, one fifth of the daily salt intake comes from cured and processed meats, wherein bacon and ham were the main contributors at 0.925 g/day (Safefood, 2008). Considering the high contribution of these products to the dietary sodium intake, specific salt reduction strategies for these products would have a great impact.

Salt has an important role in meat products as it not only provides the characteristic salty taste and flavour, but it is also essential in the development of the adequate texture—through water binding properties—and acts as preserving agent (Desmond, 2006; Puolanne & Halonen, 2010). Therefore, any reformulation of meat products involving salt reduction should be accompanied by a thorough analysis of their sensory acceptance, physicochemical properties and stability. There has been plenty of work on the effect of salt level on these properties in several meat products (Fellendorf, O'Sullivan, & Kerry, 2015, 2017; Fougy et al., 2016; Lorenzo, Fonseca, Gómez, & Domínguez, 2015; Purrinos et al., 2011; Ruusunen et al., 2005; Samapundo et al., 2013; Taormina, 2010; Tobin, O'Sullivan, Hamill, & Kerry, 2012a, b, 2013; Ventanas, Puolanne, & Tuorila, 2010) but only a few analysing the three aspects altogether (Aaslyng, Vestergaard, & Koch, 2014; Yotsuyanagi et al., 2016). The primary strategy for salt reduction in meat products has been the use of salt replacers, mainly chloride salts (Armenteros, Aristoy, Barat, & Toldrá, 2012; Desmond, 2006; Fellendorf, O'Sullivan, & Kerry, 2016a, b; Lorenzo, Cittadini, Bermúdez, Munekata, & Domínguez, 2015). However, with the growing interest for clean label products, there is need to ascertain if salt can be reduced without the addition of any replacer. The vast majority of the literature on this field corresponds to comminuted meat products for the reason that the recipe can be tweaked more easily, as in contrast with whole-muscle cured products where the meat and fat content cannot be altered. It is also important to highlight the role of lean meat, as it has been reported that an increased meat protein content reduces the perceived saltiness of the products (Ruusunen et al., 2005).

The aim of this study is to determine the minimum acceptable salt levels in terms of functionality, both sensorial and physicochemical properties, and microbial stability in bacon and cooked ham products.

2. Materials and Methods

2.1. Preliminary investigation of levels of salt in commercial products throughout Europe

A review study was conducted on declared salt levels of bacon and cooked ham from six different European countries: Germany, France, Ireland, Italy, Spain and the United Kingdom. In each of these countries, an online search of several retailers was conducted and salt content of different brands and types of the aforementioned products were obtained from their nutritional labels (113 and 223 bacon and ham samples, respectively).

2.2. Survey of levels of salt in Irish cured meat products

In order to get a preliminary indication of the levels of salt in typical commercial products, bacon and ham products were purchased from four different Irish retailers; including three different types of cooked ham products (n=30): *premium*, formed and reformed ham (with added and no added water); four types of bacon rashers (n=23): back and streaky (smoked and unsmoked versions of each), and two types of joints (n=16): bacon and ham. For each sample the package was opened, fully homogenised in a Robot Coupe (R101, Robot Coupe SA, France) and analysed in triplicate for proximate composition and salt.

2.3. Production of whole-muscle cured meat products

2.3.1. Reduced-salt formulations for back bacon rashers

A study was designed to investigate salt levels in unsmoked back bacon rashers and premium cooked ham that were reduced compared to those observed in the commercial products. The effect of simply reducing the salt content was examined—without addition or substitution using replacers or any extra ingredients, other than water, salt and sodium nitrite—on their sensorial, physicochemical and microbial properties.

Pork loins of eight pigs were purchased from a meat supplier (Ballon Meats, Raheen, Ireland) and transported to the meat processing facility at Teagasc Food Research Centre Ashtown. Four different brines were prepared containing only salt and sodium nitrite (150 ppm). Salt levels were as follows: 2.88 % (B2.9-Control), 2.50 % (B2.5), 2 % (B2) and 1.5 % (B1.5). These levels were selected according to the results from the survey as discussed in section 2.2. Each loin was cut in half and was randomly assigned to a different formulation; hence, each formulation was repeated four times. The half-loins were pumped to 113 % of their green weight using a 20-needle brine injector (Inject-O-MAT type PSM-21, Dorit Maschinen, Handels AG, Switzerland). The injected loins were weighed, vacuum packed and left to mature at 0-4 °C for 48h. The bacon was frozen to -5 °C before slicing (3 mm thick) and vacuum packed for future analysis.

2.3.2. *Premium* cooked ham

Sixteen topside muscles were purchased from an Irish supplier (Rosderra Irish Meats Group, Edenderry, Ireland). The muscles were trimmed of excess fat and stored at 2±2 °C for 24h. Brines were prepared for 120 % injection rate and target levels of 150 ppm sodium nitrite and 2 % (H2.0-Control), 1.6 %(H1.6), 1.2 %(H1.2) and 0.8 %(H0.8) salt (NaCl). These levels were selected according to the results from the survey as discussed in section 2.2. Each formulation was repeated four times. Muscles were tumbled (Dorit Vario-Vac VV-T-50, Dorit Food Processing Equipment Ltd., Switzerland) for 6h at 6 rpm on intervals of 30 min work/rest periods under chilling conditions (2-4 °C). The muscles were then netted, vacuum packed and steam cooked at 85 °C to a core temperature of 72 °C, a chill water shower was applied for 30 min and the hams were then stored for 24h at 2±1 °C. The hams were weighed throughout the process and cook loss was calculated. The cooked hams were sliced and vacuum packed for subsequent analysis.

2.4. Physicochemical properties

Fat and moisture were determined using the Smart System 5 microwave and NMR Smart Trac rapid Fat Analyser (CEM Corporation USA). Protein concentration was determined using a LECO FP328 (LECO Corp., MI, USA). Salt was calculated from chloride concentration, chloride anions were titrated in ashed (by furnace) samples with silver nitrite using the Mohr method. Colour was analysed using a Ultrascan XE spectrophotometer (CIE L*a*b system); reflectance measurements were also obtained and the cured colour ratio was calculated following the equation: ratio=650 nm/570 nm (AMSA, 2012). All values were the average of at least triplicates for each of the four batches per formulation. For each batch, four bacon slices were weighted and then cooked on a grill (190 °C) for 2 minutes on each side. Cooked samples were left at room temperature to cool down and weighted, the cook loss was calculated. Maximum force (N) was assessed on bacon cooked slices using an Instron Universal Testing Machine (Instron Ltd., High Wycombe, UK) with a 10 blade Kramer shear cell. Texture profile analysis (TPA) and expressible moisture were carried out on ham slices (20 mm thick) using the same instrument with a 25 mm circular flat disk and a 500 N load cell, following the methodology as in Resconi et al. (2015). Texture analyses were performed in four samples per formulation and batch.

2.5. Microbial analysis

Vacuum packed slices of bacon and cooked ham were stored in a walk-in cooler at 2±1 °C prior to microbiological analysis (in duplicate of pooled samples) at different time points. The ISO 4833-2:2013 and 15214:1998 were followed for the analysis of total viable counts (TVC) and lactic acid bacteria (LAB), respectively. Water activity was measured in triplicate at room temperature with the Aqualab Lite meter (Decagon Devices Inc., Pullman, WA) following manufacturer's instructions.

2.6. Sensory analysis

The sensory acceptance test was conducted using untrained assessors (n = 24–28) in the age range of 21–65, chosen on the basis that they are consumers of ham and back bacon products (Stone, Bleibaum, & Thomas, 2012). The experiment was conducted in sensory booths at room temperature conforming to the International Standards (ISO, 1988). Sample presentation was randomized according to William Latin squares to balance the first-order carryover effects. Separate duplicate sessions were prepared for bacon and ham analysis; ham samples were cut (3x3 cm) and stored at 3±1 °C right before analysis, while bacon slices were cooked at 190 °C on a grill for 2 min on each side, cut (4x2.5 cm) and kept warm in an electric bain-marie (Parry Group Ltd., Derby, UK). The panellists were asked to evaluate on a 10 cm hedonic scale the following attributes: liking of appearance, colour, texture, flavour and overall acceptability scale as a measurements of the consumers' reaction towards the product. The assessors then participated in a ranking descriptive analysis (RDA) (Richter, de Almeida, Prudencio, & de Toledo Benassi, 2010) using a list of sensory attributes measured on an intensity line scale. The list of descriptive terms was determined through the development of a consensus list of the most important terms as initially defined by an expert panel—who tested the products initially—but also through consensus with the panel. For the back bacon rashers these attributes were: redness, tenderness, juiciness, fibrous, saltiness, meaty flavour, metallic flavour and sweet aftertaste; and for the cooked ham: redness, tenderness, juiciness, saltiness and meaty flavour. For each of the sessions, panellists were presented with four samples, in both hedonic and RDA. Compusense five software (Compusense Inc., West Gelph, Canada) was used for the design and run in the panellists' booths. For the bacon samples, the appearance, colour and redness attributes were evaluated in vacuum packed raw samples.

2.7. Statistical analysis

Data were checked for normality and homoscedasticity using Saphiro-Wilk and Levene tests, respectively. Differences in experimental and labelled salt content were determined by paired samples student t-test. The rest of the physicochemical and the hedonic sensory data (mean of the replicates per panellist) were analysed using one-way ANOVA and Fisher's LSD post hoc test (Carmer & Swanson, 1973). For water activity and microbiological data a two way ANOVA was conducted using storage time and formulation as fixed factors and taking into account the interaction. For data not conferring with normality and/or equality of variances, Kruskal Wallis non-parametric test was used instead. All these analysis were done using agricolae-package in R studio (Mendiburu, 2016; R, Core Team 2015). ANOVA-Partial Least Squares regression (APLSR) was used to study the correlation between the descriptive sensory attributes and formulations. The X-matrix was designed as dummy variables (0/1) for the different formulations and as the Y-matrix the sensory attributes. Regression coefficients were analysed by Jack-knifing, which is based on cross-validation and stability plots (Martens & Martens, 2001). This analysis was performed using Unscrambler X 10.3 (CAMO Software AS, Oslo, Norway). Assessor's performance was analysed by means of the general configuration and residual variance, obtaining no significant discrepancies among panellists.

3. Results and Discussion

3.1. Review study of declared salt content in selected cured meat products

Seventy-five countries around the world, of which thirty four are European, have set salt reduction initiatives at a national or supranational level, some of them including specific targets for meat products (Trieu et al., 2015; WHO, 2013). Setting targets and guidelines help to mobilise the industry into a level playing field to successfully reach the desired levels (Frieden, 2016). Despite the European common market, there are no specific European guidelines to harmonise the target salt levels for any foodstuff and broad variations within the same type of products should be expected (Newson et al., 2013). In our study, declared salt content for both bacon and ham samples differed between the products and countries where the online review was performed (Table 1). Salt levels were higher for bacon products than for ham products in all the countries. The country/ies with lower declared salt content differed depending on the selected product, showing that this variation could be attributed not only to the differences within products (i.e.: back bacon rashers vs. streaky bacon, premium ham vs. reformed ham), but also the distinct salt reduction strategies and particular consumer behaviour in relation to salt consumption (Trieu et al., 2015; WHO, 2013). These significant differences among the selected European countries highlight that there is room for salt reduction within Europe and that consumers could adapt to lower levels of salt. Willems, van Hout, Zijlstra, and Zandstra (2014) found that soups with 32 % less salt were liked as much as the regular salt soups when consumed at home. The number of different samples found for each of the products might reflect that ham products are more consumed than bacon products, or at least that a wider variety can be found in the European markets. Some of the UK bacon samples (not included in the analysis) had the salt content per cooked slice which can be more realistic for the consumer point of view, but this impeded a proper comparison with other samples. Furthermore, the portion weight differed among samples and countries and hence making it more difficult for the consumer choice, as the nutritional information per 100 g is not always presented in a similar way. We also encountered some difficulties in finding online nutritional labelling from the German retailers. For this reason, more effort should be put on finding the acceptable salt levels in different products. Standardised European guidelines/objectives could help in the reduction of salt consumption, including a more clear and useful labelling.

3.2. Salt content in commercial Irish cured meat products

The Food Standards Agency from UK (FSA) and the Food Safety Authority of Ireland (FSAI) have agreed guidelines for the meat industry in order to reduce the salt content of several products, including bacon and ham. In the case of bacon products the FSAI agreed guidelines in 2012 were 3.3 g salt/100 g and the FSA salt targets for 2017 are 2.88 g/100 g. The FSA 2017 targets for salt in ham products is 1.63 g/100 g, the FSAI has not yet established a guideline for this product. Results from the survey in cured meat Irish products can be compared with these guidelines and are presented in Table 2. Bacon samples from Irish retailers had mean salt contents below the established guidelines both from the FSAI and FSA; however, salt content in most of the ham samples was significantly higher than the target level of 1.63 g/100 g (Table 2). Neither the different type of bacon products, nor the use of smoking in the process impacted the salt content of the bacon samples. Nonetheless, ham type (joint, premium, formed, reformed) was a significant factor when analysing the salt content. The ham joints (raw) had the highest salt content and the formed and reformed ham the lowest. No significant differences in salt content were found between the samples with added and no-added water. As salt, fat and meat content contribute to the flavour and perceived saltiness of the meat products (Desmond, 2006) the specific type of meat product should be taken into account when establishing targets. Declared salt content of the different samples are also presented in Table 2. Back bacon rashers, ham joints and formed ham had declared salt levels significantly higher than the experimentally observed levels.

For the following study (identifying minimum acceptable salt levels) baseline salt level for premium ham was established from this commercial survey (2 %) (Table 2). As the back bacon rashers had levels below the guideline from FSA, this value was selected instead (2.9 %).

3.3. Reduced-salt cured meat products

3.3.1. Physicochemical characteristics

Effect of salt reduction on proximate composition, cooking loss, instrumental texture and colour is presented in Table 3 (bacon) and Table 4 (ham). Even though non-significant, variation of fat content in the bacon samples was important; with no high variations in the rest of the macronutrients (Table 3). Regarding ham products macronutrient composition did not significantly differ (Table 3). Salt levels for both products were significantly different within each formulation ($p<0.05$). The experimental salt levels were close to the designed ones with more difference in the lowest salt bacon and ham. pH of bacon and ham was not affected by salt reduction, in accordance with several studies in different meat products (Aaslyng et al., 2014; Lee & Chin, 2011; Sofos, 1983; Yotsuyanagi et al., 2016).

The lower the salt content the higher the cooking loss for both bacon and ham, although this was only significant for some samples of the former (Table 3, 4). Salt plays an important role in the water binding properties of meat and increased cooking losses in reduced salt meat products have been reported elsewhere (Jiménez-Colmenero et al., 2010; Lee & Chin, 2011; Puolanne, Ruusunen, & Vainionpää, 2001; Ruusunen et al., 2005; Tobin et al., 2013). Aaslyng et al. (2014) reported a lower limit of 1.74 % salt content in emulsion sausages in order to not affect the processing yield. In our case, the significant increase in cooking loss in bacon took place when reducing the salt content from 1.96 % to 1.24 %. It is important to remark that neither the bacon nor the hams prepared in this study had any other additive apart from nitrite, explaining, at least partly, the high values and variability of the cooking loss. Furthermore, no effect of salt reduction on cooking loss of frankfurters, streaky bacon and reformed ham has been also reported (Aaslyng et al., 2014; Choi et al., 2014; Yotsuyanagi et al., 2016). In relation to ham samples, expressible moisture was also analysed and the sample with the lowest salt level (0.8 %) had a significant lower value compared with the samples with 2 and 1.6 % salt (Table 4). Whereas the cook loss gives us an idea of the water that could not be retained during the cooking process, expressible moisture is a measurement of the water released in the final product when an external force is applied. This attribute can be correlated with the juiciness of the product and in our study the sample H0.8—with the lowest in expressible moisture— also had a negative and significant correlation with juiciness (Tables 4, 5).

Instrumental colour measurements were unaffected ($p>0.05$) by salt reduction (Tables 3, 4). The cured colour index was higher for the bacon samples and always in the range of excellent cured colour (>2.2). However, the ham samples were all in the range of noticeable cured colour (1.7-2.0) according to AMSA (2012). Lee and Chin (2011) found no differences in colour with salt reduction and Greiff, Mathiassen, Misimi, Hersleth, and Aursand (2015) found an increase in the whiteness and decrease in the colour-hue, both in formed ham.

Salt content is important for the texture of meat products as it has a large impact on the water holding capacities that will affect the product texture (Puolanne & Halonen, 2010). Reducing the salt content below 2 % significantly increased the hardness of the bacon (cooked slices), but no significant differences were found within salt levels 2-2.9 % (Table 3). Salt reduction also increased the hardness of the ham samples, but in this case the significant differences were observed in samples H1.2 and H0.8 (Table 4). Chewiness is defined as the energy required to masticate a solid food; ham chewiness was negatively correlated with salt content and each decrease in salt level increased the chewiness significantly. These results are in agreement with those found by Tobin et al. (2013) and Pietrasik and Gaudette (2014) where lowering the salt content, in breakfast sausages and restructured ham, respectively, significantly increased the hardness of the samples. A non-significant increase in hardness and shear force with salt reduction was observed by Lee and Chin (2011) in reformed ham. On the other hand, Fellendorf et al. (2015) observed the opposite effect in white pudding, the lower the salt content the lower the instrumental hardness. Differences in salt levels, type of meat product and composition can be the reason of these discrepancies.

3.3.2. Microbial stability

Salt is an important ingredient in the manufacturing of processed meats due to its capacity to reduce the water activity (a_w). This reduction favours the growth of gram-positive bacteria instead of gram negative bacteria thus preserving the food from spoiling organisms (Feiner, 2006). This effect is not the only antimicrobial action of salt, it also interferes with substrate utilization and electrolyte imbalance inside the cells and ion chloride might be toxic for some bacteria (Taormina, 2010). Bacon products had higher salt levels than ham products and this was also reflected in the lower a_w they presented (Tables 3, 4). A 13 % and 20 % reduction of salt content in bacon and ham, respectively, did not significantly affect a_w level, but lower levels significantly increased a_w. Significant reduction of a_w levels were also found by Laranjo et al. (2017) when reducing in half the salt content of dry cured blood sausages. When reducing salt strategies are applied is important to maintain the a_w values as low as possible, as this has been proved to be effective in reducing the risk of *Listeria monocytogenes* growth (Samapundo et al., 2013).

Total viable counts were significantly affected by formulation and storage time increasing with time and salt reduction (Fig. 1, 2). In the case of bacon, TVC counts were stable up to 17 days for the samples B2.9 and B2.5. However, at this time of storage, a noticeable increase was observed in sample B1.5 and a slight one in B2.0. By the end of storage (31 days), TVC counts were significantly higher in samples B1.5 and B2.0 than in B2.9 and B2.5 (Fig.1). The latter had counts below 6 logs cfu/g considered the acceptable limit for this type of product (Aaslyng et al., 2014; BMPA, 2015). For ham samples, the counts increased significantly during storage, reaching higher levels for the samples with the lowest salt content (Fig. 1). The dominant spoiling bacteria in meat products stored under vacuum conditions are LAB (Borch, Kant-Muermans, & Blixt, 1996) and this was also corroborated in this study where LAB accounted for the majority of the TVC in both products (Fig. 2). Nonetheless, whereas in bacon products at the end of storage LAB accounted for more than 90 % of the TVC, in ham samples some important differences can be observed. At the end of storage samples H2.0 and H1.6 had LAB counts corresponding to approx. 80 % of the TVC while in samples H1.2 and H0.8 this figure got up to more than 90 %. These results are in agreement with Fougy et al. (2016) who found higher spoilage and lower bacterial diversity when reducing the salt content in pork sausages.

In terms of expected shelf life due to microbial growth we set up a limit of 6 log cfu/g as there is no legal limit established but we found that at this level, undesired odours and changes in colour and texture were starting to appear. In the case of bacon, samples B1.5 and B2.0 would reach this level before one month of storage—shelf life of commercial products is between 30 and 40 days—while samples B2.5 and B2.9 would reach the value a fortnight after. Similar pattern was observed for ham products, samples H0.8 and H1.2 would reach expected shelf life at 24 and 28 days, respectively, while for sample H1.6 and H2.0 the expected shelf life would be 37 and 39 days.

3.3.3. Sensory properties

Salt reduction impacted the sensory properties of both bacon and ham, but it is in the latter where we found more significant differences (Table 5). With respect to the hedonic characteristics, the reformulation of the bacon samples did not significantly impact the scores with the exception of appearance (Table 5). All mean values in the bacon characteristics were above 5 (out of 10), showing that the salt reduction did not dramatically affect the sensory perception. On the other hand, salt reduction in ham products significantly affected the perception of texture, flavour and overall acceptability (Table 5). In this case, sample H0.8 was scored significantly lower than the rest for these attributes. Contrasting results have been reported in hams at similar salt levels; while Pietrasik and Gaudette (2014) found no differences in flavour and overall acceptability in reduced salt hams (1.2-0.8 %), Lee and Chin (2011) observed higher liking in flavour and acceptability for hams with higher salt content (1.5-1 %). This could point out that salt reduction of premium cooked ham below 1.2 % might induce negative perception of the samples, although the exact acceptability threshold should be addressed in a consumer sensory study.

Similarly to the hedonic assessment, the RDA showed that the descriptive terms were more affected in the ham products than in the bacon products, as it can be clearly observed in the number of significant regression coefficients (Table 5) and the disposition of the samples with respect to the intensity attributes in the APLSR plots (Figs. 3, 4). For the bacon samples, it is the saltiness and the redness the main attributes differentiating the formulations, as shown in the first component where they are on the extreme right part (Fig. 3.). The rest of the attributes are around the 0 value and, consequently, cannot be considered as good discriminators among the formulations. However, for the ham samples all the attributes are far from the centre and therefore have the ability to discriminate between the products (Fig. 4.).

Even though no differences were observed in the instrumental measurement of colour of bacon and ham (Tables 3, 4), a correlation with the perceived redness intensity—the higher the salt content the more redness intensity—was found by the panellists (Table 5), albeit only significant for the B2.9 sample. These results are in agreement with Ventanas et al. (2010) where bologna type sausages with high salt content were perceived with a more intense colour. Texture intensity attributes were affected by the salt content in both bacon and ham samples. Salt reduction in both meat products decreased the tenderness and juiciness intensity (Table 5). Sample H0.8 was significant and negatively correlated with these two attributes, whereas H2.0 did significantly correlate in a positive manner. Even though non-significantly, negative correlations were also observed in B1.5 and H1.2 samples, and a clear trend of increased juiciness, tenderness and fibrous perception with higher salt content were also observed. Increased juiciness and more tenderness with higher salt content have been reported in different meat products such as frankfurters and sausages (Hand, Hollingsworth, Calkins, & Mandigo, 1987; Tobin et al., 2012a, 2013). But different effects of more added salt on sensory characteristics have been also reported, firmer and juicier beef patties, reformed ham and sausages (Lee & Chin, 2011; Ruusunen et al., 2003a, b; Tobin et al., 2012b), and reformed hams with same hardness (Greiff et al., 2015).

The lower the salt content the lower the saltiness perception for both bacon and ham samples; this can be observed in the decreasing trend of the coefficients (Table 5) and the position in the APLSR plots (Fig. 3, 4), where samples are in increasing salt content from left to right. The negative correlation became significant at 1.5 % and 0.8 % salt content for bacon and ham samples, respectively. Meaty flavour intensity followed the same trend as the saltiness but only for the ham products (Table 5). In the case of bacon, the rest of the flavour attributes (meaty flavour, metallic and sweet aftertaste) had non discriminant power.

In summary, our data shows that FSAI/FSA salt target levels could be achieved without negatively affecting the sensory perception of ham and bacon, although a consumer study should be performed to confirm these results.

4. Conclusions

Despite the efforts made by different health organisations in order to reduce the salt content in foodstuff, standard European guidelines are lacking in this matter. For the same type of meat product—at least with regards to bacon and ham— European consumers are exposed to different salt levels and diverse labelling depending on their country of residence. If lower salt levels for bacon and ham are already accepted elsewhere it means there will be room for salt reduction locally.

Our results suggest that actual salt levels in the Irish back bacon and premium cooked ham could be substantially reduced compared to what we observed commercially (34 % in bacon and 19 % in ham) with a simple approach—without the use of any extra additive/ingredient—and not affecting the sensory, physicochemical and microbiological properties of the products. These products comply with the salt content guidelines from the FSAI; the premium cooked ham would be on the proposed salt target and the back bacon rashers would reduce the target even further. With regards to this bacon product it could be labelled as *reduced salt* according to the European Regulation EC 1924/2006. Product quality and safety would be compromised if further salt reduction is applied with no other corrective measures.

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Table 1. Declared salt content of bacon and cooked ham in selected European countries

Country	Bacon		Ham	
	n	Salt (g/100 g)	n	Salt (g/100 g)
France	12	2.70±0.75[ab]	59	1.74±0.30[a]
Germany	7	2.86±0.64[ab]	17	2.35±0.28[d]
Ireland	33	2.60±0.47[a]	36	2.13±0.44[cd]
Italy	17	3.19±0.36[b]	26	1.77±0.29[ab]
Spain	22	2.39±0.71[a]	42	1.91±0.43[bc]
United Kingdom	22	2.72±0.45[ab]	43	2.00±0.32[bc]
Total	113	2.74	223	1.98

Mean ± SD. Within the same column different letter denotes significance (*P*<0.05)

Table 2. Experimentally determined salt levels of bacon and ham from Irish retailers

Product	n	Salt (g/100 g)	Declared salt (g/100 g)	p-value (paired comparison)
Bacon				
Joints	6	2.81±0.84[a]	2.27±0.66[a]	0.142
Back bacon rashers	17	2.41±0.64[a]	2.75±0.24[b]	0.024*
Streaky rashers	10	2.53±0.56[a]	2.72±0.36[ab]	0.52
Total	33	2.55±0.70	2.60±0.47	0.75
Ham				
Joints	6	2.37±0.37[b]	2.90±0.26[b]	0.028*
Premium ham	8	2.02±0.94[ab]	1.98±0.46[a]	0.91
Formed ham	14	1.66±0.38[a]	1.99±0.23[a]	0.031*
Reformed ham	8	1.59±0.52[a]	1.95±0.13[a]	0.065
Mean Cooked	30	1.74±0.61	1.98±0.28	0.053
Total	36	1.84±0.62	2.13±0.44	0.009**

Mean ± SD. Within the same column and product different letter denotes significance (*P*<0.05)

Table 3. Physicochemical properties of back bacon rashers

	Sample			
	B2.9	B2.5	B2.0	B1.5
Moisture (%)	60.00±1.25	62.18±1.61	64.54±4.03	62.34±3.29
Fat (%)	23.11±2.21	19.96±2.76	17.94±5.44	21.35±4.11
Protein (%)	14.93±1.05	15.71±1.42	15.93±0.81	15.49±0.77
Ash (%)	3.82±0.17[c]	3.64±0.16[c]	2.76±0.12[b]	2.00±0.06[a]
Salt (%)	2.99±0.12[d]	2.67±0.20[c]	1.96±0.06[b]	1.24±0.04[a]
pH	5.41±0.23	5.42±0.23	5.41±0.21	5.49±0.11
Water activity	0.974±0.002[a]	0.976±0.003[a]	0.981±0.002[b]	0.983±0.002[b]
Cook loss (%)	22.91±3.44[a]	25.89±3.33[ab]	29.01±2.85[b]	38.01±2.07[c]
Hardness (N)	452.74±25.26[a]	446.81±14.66[a]	429.21±23.45[a]	595.22±68.37[b]
L*	50.70±2.73	50.93±2.90	52.94±3.09	53.53±1.49
a*	9.43±1.18	9.43±1.85	8.09±0.99	8.49±1.38
b*	10.36±0.44	10.79±0.33	11.08±0.85	11.20±0.37
Chroma	14.02±1.02	14.38±1.32	13.74±1.02	14.09±0.76
Hue	47.82±2.92	49.13±5.28	53.91±3.38	53.04±4.94
Cured colour	2.35±0.22	2.39±0.26	2.23±0.05	2.82±0.14

Mean ± SD. Within the same row different letter denotes significance (P<0.05). B2.9, B2.5, B2.0, B1.5: back bacon rashers with NaCl levels of 2.9%, 2.5%, 2% and 1.5%, respectively.

Table 4. Physicochemical properties of cooked ham samples

	Sample			
	H2.0	H1.6	H1.2	H0.8
Moisture	68.46±1.26	69.06±1.21	69.07±2.32	67.89±0.78
Fat	4.36±1.36	3.98±2.88	3.82±0.79	4.06±1.20
Protein	27.08±0.76	26.85±2.03	26.38±2.01	28.40±1.13
Ash	2.41±0.22[d]	2.04±0.15[c]	1.68±0.12[b]	1.23±0.09[a]
Salt	1.92±0.23[d]	1.55±0.15[c]	1.21±0.08[b]	0.70±1.18[a]
pH	5.75±0.15	5.74±0.21	5.83±0.12	5.79±0.12
Water activity	0.983±0.001[a]	0.984±0.001[a]	0.988±0.002[b]	0.989±0.001[b]
Cook Loss	24.42±3.49	25.68±4.23	26.70±4.55	30.85±2.97
Expressible Moisture	3.28±0.25[b]	2.89±0.29[b]	3.06±0.44[ab]	2.43±0.36[a]
Hardness	177.13±19.64[a]	195.28±10.96[a]	280.56±14.65[b]	259.71±21.33[b]
Chewiness	426.42±45.79[a]	511.12±12.41[b]	722.03±52.35[c]	804.34±34.58[d]
Springiness	6.02±0.02[a]	6.37±0.39[a]	6.62±0.23[ab]	6.71±0.35[b]
Cohesiveness	0.40±0.00	0.41±0.01	0.39±0.04	0.46±0.06
L*	70.81±2.35	71.57±2.08	72.87±4.09	72.79±3.57
a*	9.69±0.93	9.27±0.59	8.37±1.21	8.48±1.13
b*	9.61±0.33	9.49±0.36	9.26±0.62	9.39±0.20
Chroma	13.67±0.64	13.27±0.64	12.51±1.22	12.68±0.88
Hue	44.84±3.12	45.73±1.08	48.06±2.72	48.19±3.25
Cured colour	2.05±0.15	2.00±0.10	1.91±0.19	1.92±0.17

Mean ± SD. Within the same row different letter denotes significance ($P<0.05$). H2.0, H1.6, H1.2, H0.8: premium cooked ham with NaCl levels of 2.0%, 1.6%, 1.2% and 0.8%, respectively.

Table 5. Mean scores for hedonic attributes and beta coefficients of ANOVA Partial Least Square Regression for the intensity terms of back bacon and cooked ham

	Bacon				Ham			
	B2.9	B2.5	B2	B1.5	H2.0	H1.6	H1.2	H0.8
Mean score (±SD)								
Hedonic terms								
Appearance	6.0±1.5[a]	5.8±1.4[a]	7.1±1.4[b]	5.6±1.7[a]	5.9±1.3	5.8±1.2	5.9±1.4	5.8±1.3
Colour	6.2±1.4	6.1±1.3	6.9±1.4	6.2±1.4	5.7±1.5	5.4±1.4	5.6±1.6	5.6±1.4
Texture	6.1±1.6	6.5±1.6	6.6±1.8	6.5±1.9	6.0±1.3[ab]	6.6±1.3[b]	5.1±1.9[a]	5.3±1.6[a]
Flavour	6.2±1.6	6.4±1.6	6.9±1.6	6.6±1.7	6.6±1.2[b]	6.3±1.3[b]	5.8±1.6[b]	4.2±1.8[a]
Overall Acceptability	6.2±1.7	6.5±1.5	6.8±1.6	6.5±1.7	6.3±1.2[b]	6.4±1.3[b]	5.7±1.5[ab]	5.0±1.7[a]
Regression coefficients								
Intensity terms								
Redness	0.216**	0.089	0.033	-0.338	0.096	0.062	-0.047	-0.112
Tenderness	0.006	0.002	0.001	-0.009	0.206*	0.133	-0.100	-0.239*
Juiciness	0.101	0.042	0.016	-0.159	0.364***	0.234	-0.176	-0.422***
Fibrous	0.095	0.039	0.015	-0.149	-	-	-	-
Crunchiness	-0.031	-0.013	-0.005	0.048	-	-	-	-
Saltiness	0.448	0.186	0.069	-0.703***	0.499***	0.321*	-0.242	-0.579***
Meaty Flavour	-0.006	-0.003	-0.001	0.010	0.220*	0.142	-0.107	-0.255*
Metallic taste	-0.017	-0.007	-0.003	0.026	-	-	-	-
Sweet aftertaste	-0.078	-0.032	-0.012	0.122	-	-	-	-

B2.9, B2.5, B2.0, B1.5: back bacon rashers with NaCl levels of 2.9%, 2.5%, 2% and 1.5%, respectively. H2.0, H1.6, H1.2, H0.8: premium cooked ham with NaCl levels of 2.0%, 1.6%, 1.2% and 0.8%, respectively.

For each of the products in the hedonic terms different letter indicates significant difference among formulations

Significance of regression coefficients: **P*<0.05, ***P*<0.01, ****P*<0.001

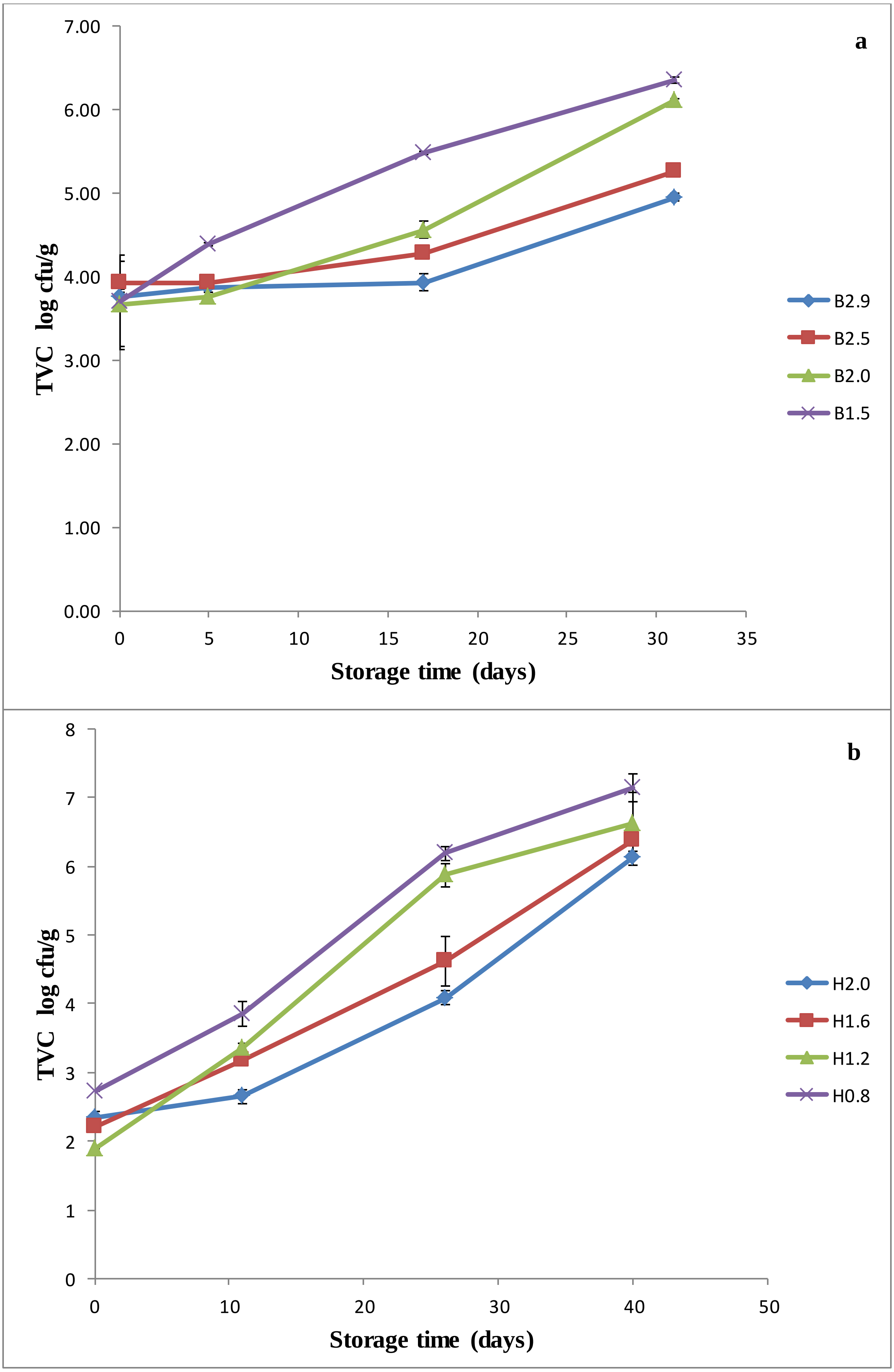
Figure Captions

Figure 1. Total Viable Counts (TVC) of back bacon (a) and cooked ham samples (b) during storage at 2 °C

Figure 2. Lactic Acid Bacteria (LAB) of back bacon (a) and cooked ham samples (b) during storage at 2 °C

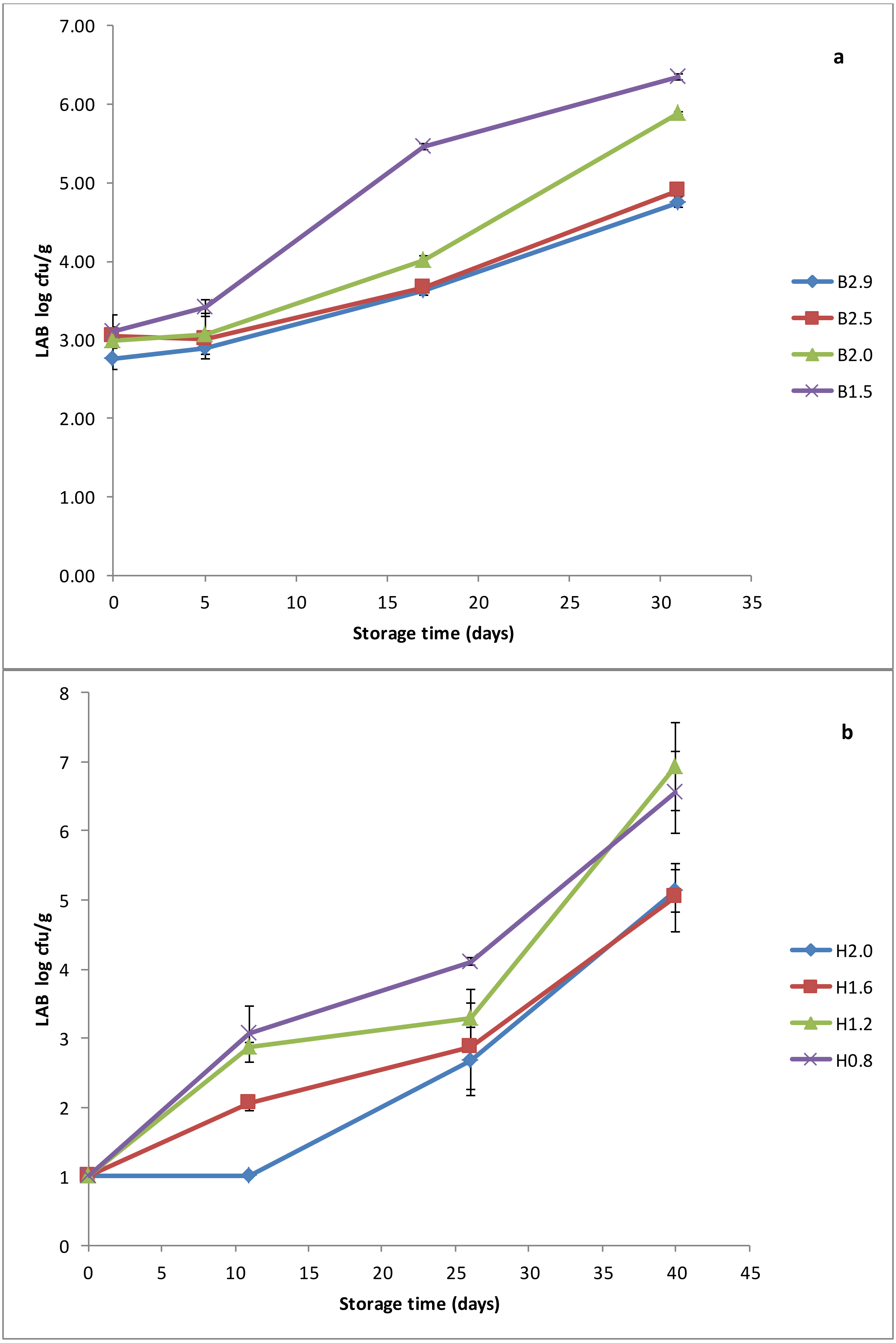
Figure 3. APLSR loadings and scores plot for back bacon rashers

Figure 4. APLSR loadings and scores plot for premium cooked ham samples



a
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
TVC log cfu/g
0
5
10
15
20
25
30
35
Storage time (days)
B2.9
B2.5
B2.0
B1.5
b
8
7
6
5
4
3
2
1
0
TVC log cfu/g
0
10
20
30
40
50
Storage time (days)
H2.0
H1.6
H1.2
H0.8

Fig 1.



a
LAB log cfu/g
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
5
10
15
20
25
30
35
Storage time (days)
B2.9
B2.5
B2.0
B1.5
b
LAB log cfu/g
8
7
6
5
4
3
2
1
0
0
5
10
15
20
25
30
35
40
45
Storage time (days)
H2.0
H1.6
H1.2
H0.8

Fig 2.

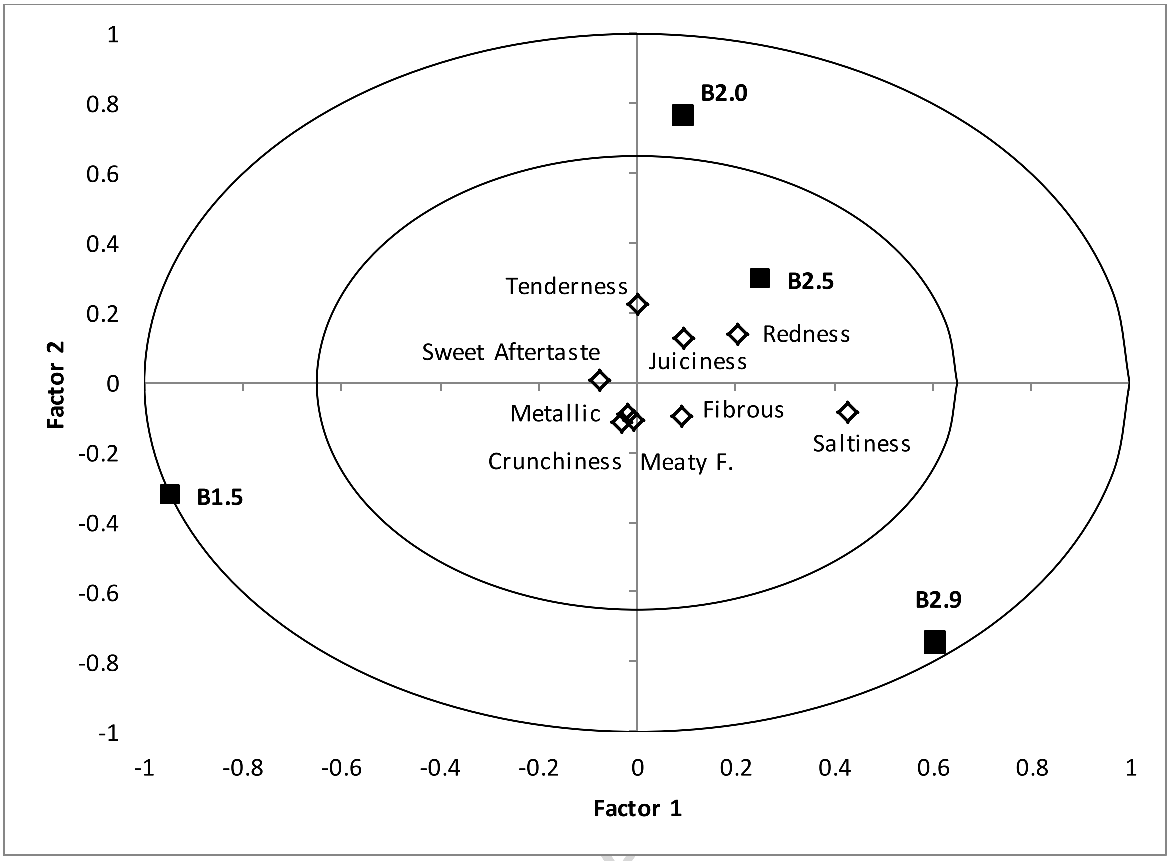
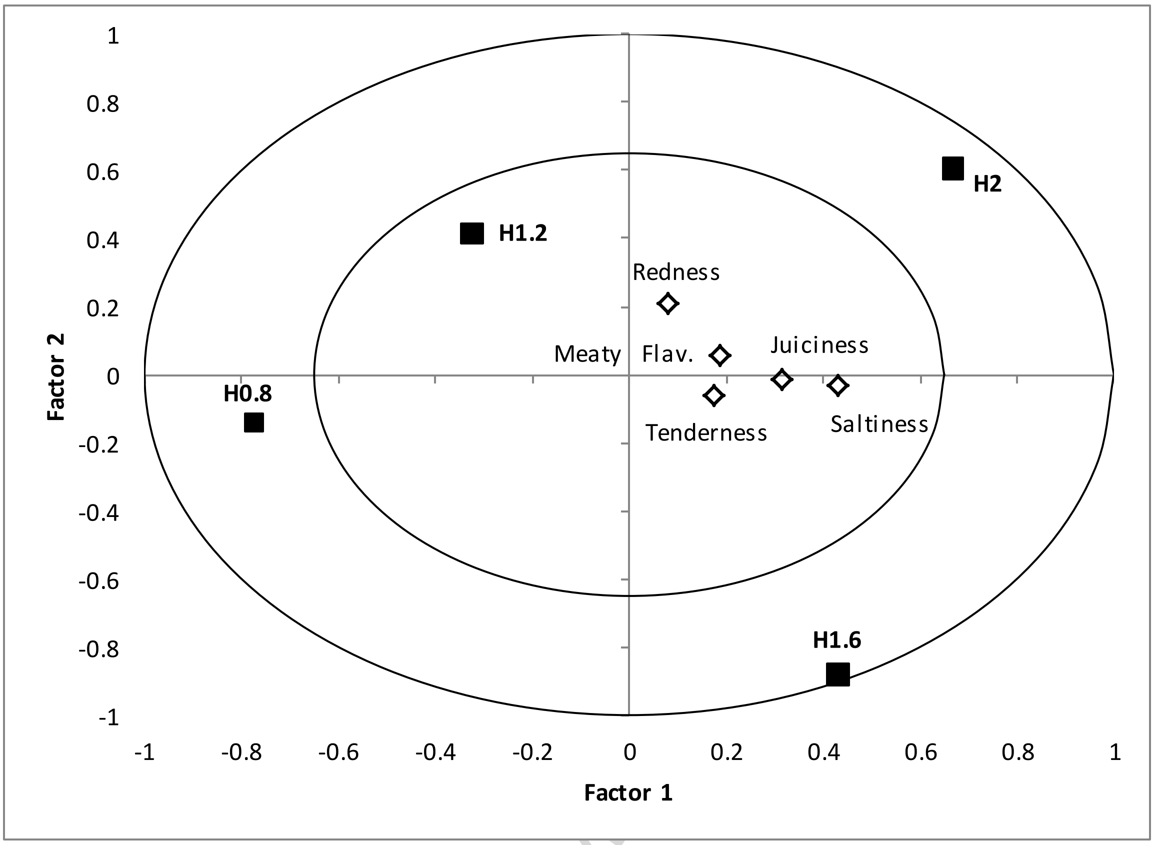

B2.0
B2.5
B1.5
B2.9
Tenderness
Redness
Juiciness
Sweet Aftertaste
Metallic
Fibrous
Saltiness
Crunchiness
Meaty F.
Factor 1
Factor 2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1

Fig. 3.



1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
Factor 2
H2
H1.2
Redness
Meaty
Flav.
Juiciness
H0.8
Tenderness
Saltiness
H1.6
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
Factor 1

Fig. 4.